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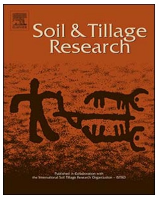

Research paper

Comparison of runoff and soil loss in different tillage systems in the Mollisol region of Northeast China

Ximeng Xu[a], Fenli Zheng[a,b,*], G.V. Wilson[c], Chao He[a], Jia Lu[a], Feng Bian[a]

[a] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A & F University, Yangling 712100, Shaanxi, PR China*
[b] *Institute of Soil and Water Conservation, CAS & MWR, Yangling 712100, Shaanxi, PR China*
[c] *USDA-ARS National Sedimentation Laboratory, Oxford 38655, MS, USA*

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ABSTRACT

Longitudinal ridge tillage is the conventional tillage method in the cold, Mollisol region of Northeast China in which furrows are oriented up and down the slope. In part due to the use of this tillage system with large slope lengths, soil erosion is a serious problem in this region. Currently, it is unclear what the best tillage system and ridge orientation is for sustainable agriculture in this region. Thus to compare the runoff and soil loss in longitudinal (LRS) and contour ridge (CRS) systems to a flat tillage system (FTS), a series of simulated rainfall experiments were conducted. A large soil pan (8 m-long, 1.5 m-wide, and 0.6 m-deep) and a side sprinkler rainfall simulation system were used in this study with the three tillage systems (LRS, CRS, FTS) under three rainfall intensities (50, 75 and 100 mm h^{-1}) at a 5° slope gradient. The results showed that runoff and soil loss in the LRS were larger than those in the CRS and FTS due to a shift in erosion pattern from sheet to concentrated flow erosion along furrows which led to shear stress increases. Contour ridge failures occurred in the 75 and 100 mm h^{-1} treatments by breaching of ridges when water stored in furrows exceeded their storage capacity. Breaching changed the runoff and soil loss by providing a large sediment source to the convergent flow. Water storage of CRS furrows was constant as rainfall intensity varied which led to overtopping during large storm conditions. Shifting conventional LRS to CRS with modifications to retain more rainwater during low to moderate rainfall events is highly recommended as this would reduce soil loss and enhance infiltration. The FTS exhibited the lowest runoff and soil loss which is recommended for the Mollisol region of Northeast China in large storm conditions.

1. Introduction

Ridge tillage is a popular agronomic practice widely used around the world with many different modifications but with the same goal to prepare a seedbed that is elevated above the natural land surface (Lal, 1990; Gürsoy et al., 2012). Ridge tillage affects soil temperature, compaction and water distribution patterns compared to flat-bed tillage, thus, it can improve seed and seedling environment for crop production by providing a drier and warmer seed bed in the spring due to the drainage effect of furrows (Benjamin et al., 1990; Fausey, 1990; Hatfield et al., 1998; Mert et al., 2006; He et al., 2010). There can also be other benefits from ridge tillage, e.g., enhanced rooting depth, improved pest management, nutrient loss control and erosion control (Lal, 1990; Hatfield et al., 1998; Liu et al., 2014a). However, the degree to which such benefits are realized depends to a large extent upon the tillage orientation and the residue management. Ridges oriented up and down the slope can foster concentrated flow which can significantly increase soil loss, and therefore intensify nutrient losses. In contrast, ridges oriented along the contour may store water in furrows, thereby, increasing infiltration and reducing soil losses (Hagmann, 1996; Shen et al., 2005; Arnhold et al., 2013). For no-till ridge systems in which ridges are formed every few years and residue is maintained on the surface between ridge formation years, crop residue protects the soil surface in the furrows from direct rainfall and slows down convergent flows (Jaynes and Swan, 1999).

In response to the climate (freezing conditions in winter and early spring; high snowmelt runoff rate in spring; rainfall mainly concentrated in summer) and topographic conditions (gentle slopes and long slope lengths), ridge tillage is the conventional tillage method in the Mollisol region of Northeast China (Chen et al., 2011; Zhang et al., 2011). Longitudinal ridge system (LRS) in which ridges are oriented up and down the hillslope, perpendicular to the contour, is the dominant

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[*] Corresponding author at: No. 26, Xi'nong Road, Institute of Soil and Water Conservation, Yangling, Shaanxi 712100, PR China.
E-mail address: flzh@ms.iswc.ac.cn (F. Zheng).

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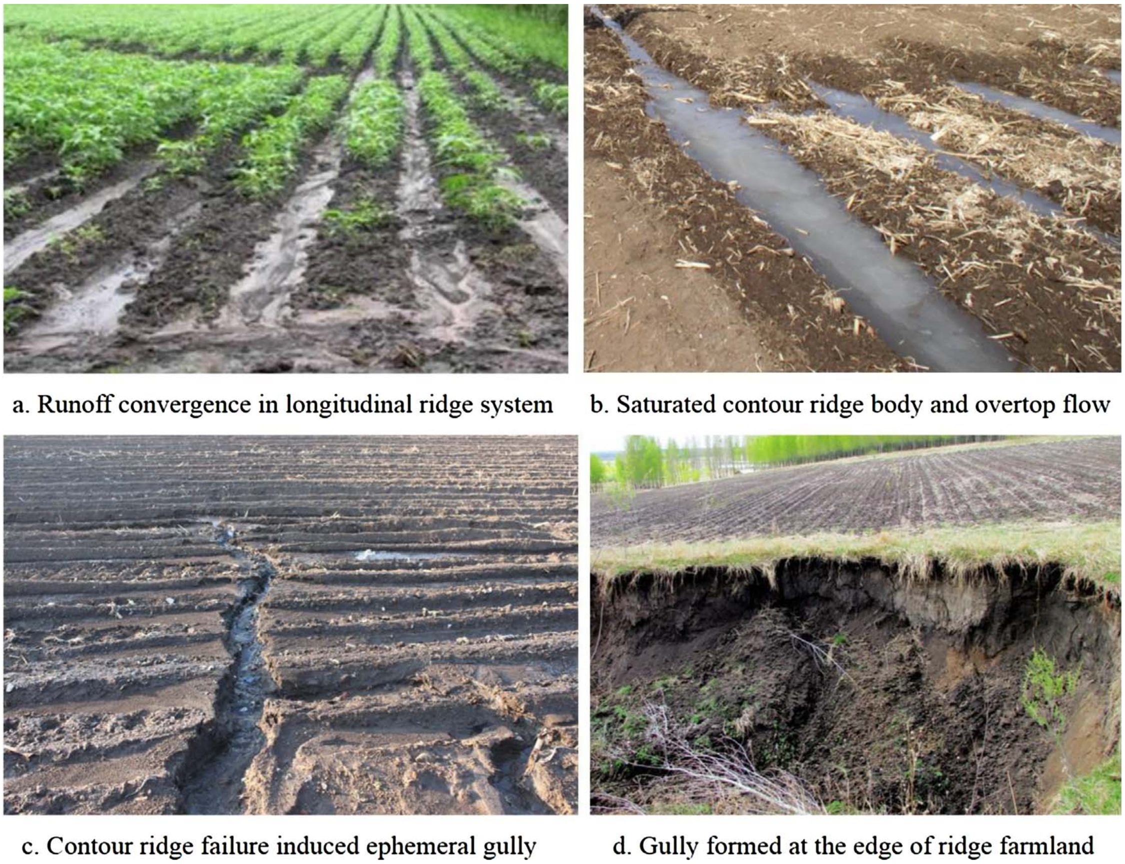

a. Runoff convergence in longitudinal ridge system

b. Saturated contour ridge body and overtop flow

c. Contour ridge failure induced ephemeral gully

d. Gully formed at the edge of ridge farmland

Fig. 1. Ridge tillage induced erosion features in the Mollisol region of northeast China.

tillage system in this region (Fig. 1a; Free, 1956; Shen et al., 2005). Contour ridge system (CRS) in which ridges are established along the contour, perpendicular to the overland flow path, is relatively rare in this region. The LRS has long been conceded as accelerating runoff and soil loss in the Mollisol region (Shen et al., 2005; Chen et al., 2008; Meng and Li, 2009), while the CRS is recognized as being more effective in increasing water infiltration (Fig. 1b) and controlling soil erosion than the LRS (Jaynes and Swan, 1999; Shen et al., 2005; Gebreegziabher et al., 2009; Liu et al., 2014a; An et al., 2015).

Contour ridging has been recognized for decades for substantially reducing erosion (Free, 1956; Reeder, 1990; Stevens et al., 2009). However, under extreme rainfall conditions, contour ridges tend to breach and, thereby, foster ephemeral gully erosion (Hatfield et al., 1998; Liu et al., 2014b). Breaching of contour ridges is a concern in Northeast China (Fig. 1c) as erosive storms can occur in the summer with short duration but high intensity and often coincide with snowmelt runoff (Fig. 1b) in spring (Li et al., 2016; Lu et al., 2016). Contour ridge stability is mainly related to ridge geometry, sloping land microtopography, soil physical properties of ridge body, and rainfall characters (Liu et al., 2014b). In RUSLE2, the contouring factor p_c is used to compute the effects of contouring on soil erosion, which is a ratio of erosion with contouring to erosion without contouring, i.e. up and downslope tillage. Experimental data shows that when ridge height is large and slope steepness is small, the contouring subfactor p_c produces relatively small values (USDA-ARS, 2008, 2013). RUSLE2 assumes contouring failure where roughness shear stress computed with Eq. (1) exceeds a critical shear stress which is determined by calibrating critical slope length values given in Agriculture Handbook 537 (Wischmeier and Smith, 1978).

$$\tau_f = q_i^{0.85714} s / n_t^{1.2857} \qquad (1)$$

where τ_f is form roughness shear stress (lbs/ft^2); the discharge rate q_i is computed as the product of excess rainfall rate (inches/hour) and the distance along overland flow path (ft); s is overland flow path steepness (%); n_t is total Manning's roughness coefficient (ft$^{1/6}$). However, data are still not sufficient to derive empirical contouring relationships to soil loss in a wide variety of environmental conditions. Thus, further work still needs to be done on the factors influencing soil erosion of the CRS, e.g., suitable ridge geometry for controlling runoff and soil loss, rainfall patterns and microtopography impacts on erosion, etc.

The fertile and productive Mollisols (Black soils) are mainly distributed in a concentrated area in the northeast China with slopes less than 7° but extensive slope lengths that range from 200 to 1000 m (Liu et al., 2011; Li et al., 2016). As a result of the high physical and chemical quality of the native Mollisols, the Mollisol region has been one of the most important grain production bases of China (Meng and Li, 2009; Lu et al., 2016). However, agronomic management over the last 100 years, in combination with high intensity rainfall in summer, snowmelt runoff, and intensive cultivation, has led to the severe runoff and soil loss and wide spread gully erosion (Fig. 1d; Zhang et al., 2007; Liu et al., 2011; An et al., 2012; Lu et al., 2016). According to the soil loss control and ecological security report made by Chinese Ministry of Water Resources and Chinese Academic of Science in 2010, surface mollic thickness was being reduced at a rate of 0.3 to 1 cm per year. The mollic thickness has decreased from 50 to 80 cm in 1950s to 20–40 cm at present as a result of water erosion following reclamation for agriculture use (Zhang et al., 2007). Less productive parent material with low organic matter content is being exposed at the surface in some areas, which greatly decreases the soil quality and reduces crop yield (Yang et al., 2016). Liu et al. (2013) reported that soil depth was the most important indicator of crop yield in the Mollisol region and every 1 cm decrease in depth results in a 2% decrease in yield. Liu and Yan (2009) reported that soil loss and gully erosion on the farmlands in the Mollisol region resulted in a 10.8 billion kg crop yield loss per year.